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Energy requirements for harvesting cassava using light farm tools in the eastern Democratic Republic of the Congo

Audry MUKE[1,2,3,4*], Nsharwasi Nabahungu LEON[2], Kokou KINCHÉ[2], Viktor VAN DE VELDE[4,5], Oswald VAN CLEEMPUT[4], Bernard VANLAUWE[3] and Pascal BOECKX[4]

[1] *Institut National pour l'Etude et la Recherche Agronomique (INERA), Station de Mulungu, Département de Gestion des Ressources Naturelles, Laboratoire des Sols et Plantes, DS Bukavu, RDC*
[2] *International Institute of Tropical Agriculture (IITA)-Kalambo station, Soil and Plant Laboratory, Poste Box 1363, Bukavu, DRC*
[3] *International Institute of Tropical Agriculture (IITA), PMB 5320, Oyo Road, Ibadan 200001, Oyo State, Nigeria*
[4] *Isotope Bioscience Laboratory - ISOFYS, Department of Green Chemistry and Technology, Ghent University, 9000 Gent, Belgium*
[5] *Ghent University, Q-ForestLab, Department of Environment, 9000 Gent, Belgium*

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* Correspondance, courriel : *audrymuke@gmail.com*

Abstract

A study was carried out at three sites in eastern Democratic Republic of the Congo (DRC) with the aim of reducing the time taken for harvesting, the energy required and the labour intensity, as well as minimising tuber damage and breakage. The performance of two harvesting tools was compared to that of the traditional hoe. The tools were the lifter1 and the lifter2. The lifter1 rests on three legs and works on the "grip and lift" principle, while the lifter2 consists of a handle with a chisel attached to it that serves as a base for lifting cassava from the ground. The results showed that using a hoe increased the time taken to uproot by 42 %, and the force required by 7 %, compared to using a lifter2. Furthermore, the heart rate recorded by the hoe was 16 % higher than that recorded by the lifter2. These results show that using the lifter2 involves moderate-intensity physical activity, whereas harvesting cassava with a hoe involves vigorous-intensity activity. However, adjustments are currently needed to improve grip on the cassava stem when using the lifter2 for harvesting. This can improve the efficiency of cassava harvesting, allowing local farmers to work more comfortably and boost their performance.

Keywords : *cassava production, harvesting tool, harvest energy requirement.*

Résumé

Besoins énergétiques pour la récolte du manioc à l'aide d'outils agricoles légers dans l'Est de la République démocratique du Congo

Une étude menée sur trois sites dans l'est de la République démocratique du Congo (RDC) visait à réduire le temps de récolte, les besoins en énergie, le niveau de travail et les dommages ou la casse des tubercules. Les performances de deux outils de récolte, le lifter1 et le lifter2, ont été comparées à celles de la houe traditionnelle. Le lifter1 repose sur trois pieds et fonctionne selon le principe « saisir et soulever », tandis que le lifter2 est constitué d'un manche auquel est attaché un ciseau servant à soulever le manioc du sol. Les résultats ont montré que l'utilisation d'une houe augmentait le temps de déracinement de 42 % et la force nécessaire de 7 % par rapport à l'utilisation d'un lifter2. De plus, la fréquence cardiaque enregistrée par la houe était 16 % plus élevée que celle enregistrée par le lifter2. Il ressort de ces résultats que l'utilisation du lifter2 est une activité physique d'intensité modérée, tandis que la récolte du manioc à l'aide d'une houe est une activité d'intensité vigoureuse. Cependant, des ajustements sont actuellement nécessaires pour améliorer la prise sur la tige de manioc au moment de la récolte avec le lifter2. Cela peut améliorer l'efficacité de la récolte du manioc et préserver l'énergie des agriculteurs locaux, qui pourront ainsi travailler plus confortablement et améliorer leurs performances.

Mots-clés : *production de manioc, outil de récolte, besoins énergétiques pour la récolte.*

1. Introduction

Cassava, *Manihot esculanta* Crantz (*Euphorbiaceae*), is a tropical, herbaceous, perennial woody shrub, with a tuberous starchy root [1]. Most of the cassava produced in the tropics is by small-scale farmers (especially in rural communities) who depend on crude implements for their field operations [2]. Cassava cultivation involves several field operations, of which harvesting is one of the most important and crucial activity [2, 3]. Cassava harvesting is the biggest challenge [4, 5], implying the highest production cost [3]. Cassava harvesting is laborious and time-consuming, involving hard work and difficulty [6 - 9]. This is a widespread problem on smallholder farms in the DRC. As a result, farmers are forced to produce cassava on a small scale, primarily for subsistence and local markets [10]. Furthermore, in eastern DRC cassava harvesting is commonly manually operated. Amponsah et al. [9] state that manual cassava harvesting is the serious bottleneck operation in cassava production. It requires about 22 - 62 person-days per hectare [11], comparable with assertions by [9] ranging from 11.1 - 31.9 person-days per hectare. The manual harvesting is usually done by hand; by lifting the lower part of the stem and pulling the roots out of the ground, and then removing the tubers from the base of the plant by hand. Tools such as a machete and a hoe can be used to assist in uprooting the tubers. These processes could be carried out with the use of mechanized equipment [8, 9, 12], involving the use of a harvesting implement, hitched to a tractor to first cut and subsequently dig up the roots [13]. This method is the most preferable one but, in eastern DRC, most cassava fields are located in places where topography is a serious challenge, making use of tractors practically impossible. Even in places where such mechanized options are available, it becomes unwise to adopt them because of the smaller field size covering just about 0.01 to 0.02 hectare. Thus, a farmer in such an area would have no choice but to harvest manually even if mechanical harvesting is affordable. Likewise, the farmer’s practice of intercropping does not favor mechanization. As an alternative, using an improved manual harvester in well-spaced cassava fields can reduce the time taken for manual cutting and uprooting by around 50 % [14]. Performance ranges from 52.2 to 121.8 hours Ha^{-1} [9]. However, it is worth noting that cassava harvesting has received little research and still continues to be very crucial in the cassava production value chain in eastern DRC. Obtaining information will be useful to engineers in their effort to design appropriate harvesting tools and implements in the future. This study aimed to reduce the time, energy and labour required for cassava harvesting in humid tropical regions of eastern DRC, while minimizing tuber damage and breakage.

2. Methodology

2-1. Study area

The study was carried out at three sites: Kabare (2°20'6'' S, 28°47'16.8'' E, 1 699 m a.s.l.), Uvira (3º22'22.33'' S, 29º08'41.56'' E, 806 m a.s.l.), and Walungu (2°37'42'' S, 28°39'57'' E, 1 777 m a.s.l.), in the humid tropical region of eastern DRC. Kabare is characterized by a bimodal rainfall pattern with a 3-month dry season [15]. Average annual rainfall ranges between 1500-1800 mm and the growing season extends to over 325 days per year [16, 17]. Fertile humic nitisols and ferralsols [18] are found because of recent rejuvenation by volcanic ashes or mudflow deposits from the outpourings of Kahuzi and Biega mountains; these soils have a high organic matter content, favorable pH and larger nutrient reserves [19]. Uvira is located at a lower altitude than the other sites. According to the Köppen classification, the climate is tropical savannah (Aw1-3), with an altitude not exceeding 1,000 metres above sea level. In this type of climate, the dry season can be severe, with some months experiencing no rainfall, and drought conditions often prevailing throughout the year. The annual average temperature is > 24°C. Mostly clay soils of the montmorillonite type are found in Uvira. The montmorillonite in the trial field is a smectite formed by neo-formation from ions released by hydrolysis and concentrated *in situ* and/or at the bottom of the slope. It is found in places in Uvira (Ruzizi plain). They are of good fertility, although heavy and difficult to work.

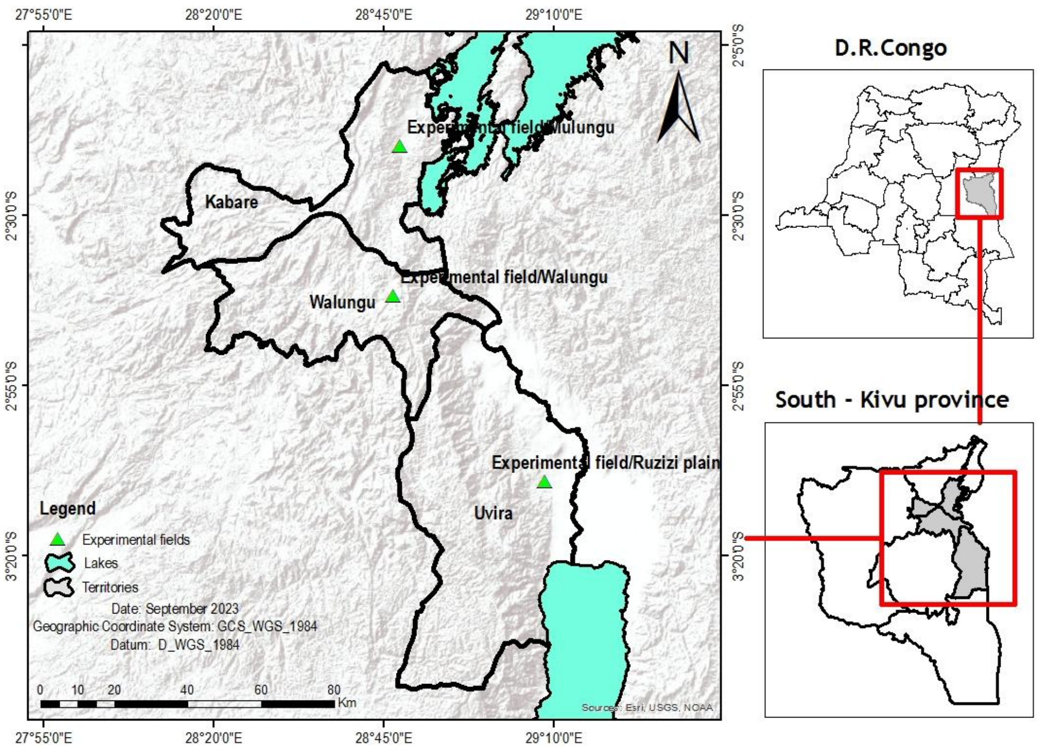

Figure 1 : *Map showing locations of the experimental fields (green triangles) in three territories, namely Kabare, Uvira and Walungu of the South-Kivu province in DRC*

Walungu is located at high altitude (> 1400 m). Its climate is marked as Cwa in the Köppen classification with an annual mean temperature between 12 – 20^{O}C. This humid subtropical climate is characterised by hot, humid summers and cool to mild winters. The average annual rainfall in Walungu ranges from 1,200 to 1,800 mm from east to west. The soils in Walungu consist of humic nitisols or ferralsols that overlie metamorphic and sedimentary rocks, and have a low pH of between 4 and 4.5 [20].

2-2. Experimental details

A split plot design with three replicates was used for this study. The main plot treatments were cassava spacing (broadcast, 1 x 1 m and 2 x 0.5 m) and cassava harvesting tools (hoe, lifter1 and lifter2), were the subplot treatments.

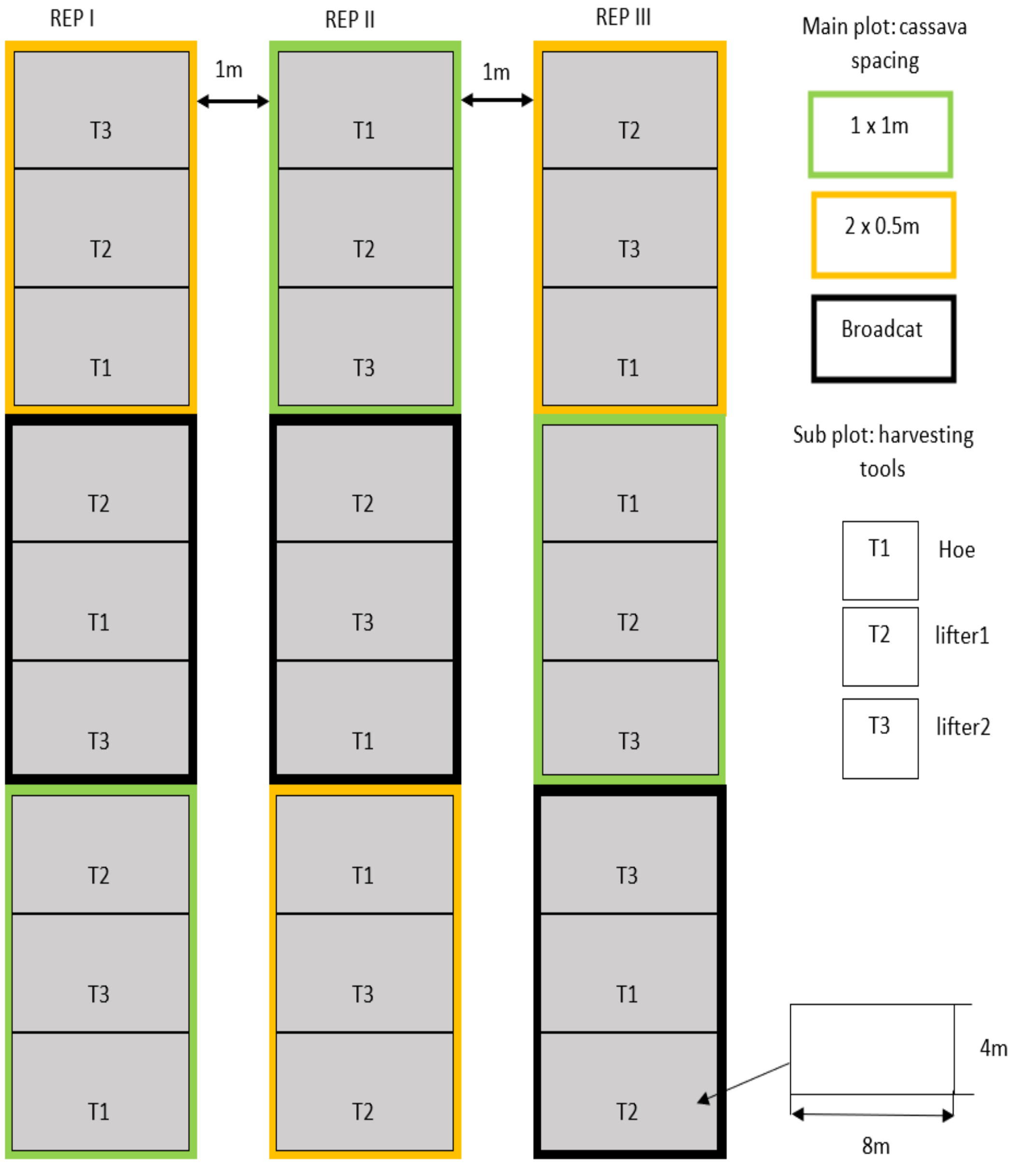

Figure 2 : *Experimental split-plot design: treatments consisted of cassava spacing: broadcast, 1 x 1 m, 2 x 0.5 m and cassava harvesting tools : hoe, lifter 1, lifter 2*

2-3. Manual harvesting tool

Manual harvesting of cassava starts with pulling out the stem at a height of 0.3 - 0.5 m above the soil surface ***(Figure 3)***.

Figure 3 : *Manual harvesting cassava: the use of the hoe (A) helping in loosening or reducing the soil forces on the cassava root tubers in order to make it easier to uproot (B) them*

The detachment of the aerial parts of the plants allows for an effective grip by the hand. Indeed, under firm rooting conditions, the hoe or digging fork is employed to dig out the soil in the root zone and to reduce the soil with restraining forces before uprooting out the tubers. Cassava is mostly harvested by hand. The lower part of the stem is lifted and the roots are pulled out of the ground. The roots are then detached from the base of the plant by hand, after the upper part of the stem and the leaves have been removed. Using a hoe helps to loosen the soil around the cassava root tubers, making them easier to uproot [10].

2-4. Improved harvesting tool

With the idea of substituting the hoe, an improved manual harvesting tool was developed with two prototypes ***(Figure 4)***.

Figure 4 : *Locally adapted improved harvesting tools (A and C) that operate according to the 'grip and lift' principle (B and D)*

The lifter1 and lifter2 harvesting tools were constructed at Bukavu (South Kivu) and Butembo (North Kivu), respectively, with the idea of reducing the hard work of farmers due to waist bending associated with the hoe ***(Figure 4)***, which usually leads to waist pains and other bodily weaknesses. Lifter1 and lifter2 operate according to the ''grip and lift'' principle. It consists of a frame to which an immovable griping jaw is attached and a chisel tip which serves as the base for lifting cassava out of the soil. The chisel tip can also be used to dig out cassava tubers, particularly in hard, dry soils where it is difficult to employ the grip-and-lift principle due to the high risk of tuber damage or breakage.

2-5. Harvesting force, heart rate, work done and harvesting capacity

Before manual harvesting, one field worker was tasked to uproot five cassava plants using a hand-hoe or the improved manual harvesting tools, lifter1 and lifter2. With the help of a stop clock, time (seconds) necessary to harvest the five plants was recorded. The average heart rate during harvesting has been measured using a calorie sensor watch (Oraimo Tempo S; MAC 78:02: B7:31: OE: 91; version V001189). The force (F) of harvesting (Newton) and work done (W) (Joule) during harvesting were calculated using ***Equations (1) and (2)***, sequentially.

$$\mathrm{F} = mg \tag{1}$$

$$\mathrm{W} = Fd \tag{2}$$

D, is the distance (cassava tuber depth) (cm) ; m, the weight of cassava tubers (kg) and g, acceleration of gravity (9.8 m s^{-2})

The harvesting capacity (timeliness of operation) for each field worker during harvesting (person-hours Ha^{-1}) was determined using ***Equation (3)***, according to [10].

$$T = \frac{10000 \text{ x t}}{\text{A x 3600}} \tag{3}$$

T, is the total harvesting capacity (person-hours Ha^{-1}); t, the total time spent in harvesting (seconds) and A, the harvested area (m^2).

A total of 45 individuals were involved in the harvest, with 15 individuals per replicate consisting of individuals of different ages, sexes and weights. The variability of heart rate, strength, work and harvesting capacity was calculated as the sum of the squared deviations of each observation from its group mean divided by the degree of freedom of error.

2-6. Agronomic parameters

The investigated agronomic parameters include the maximum tuber diameter (cm), canopy height (cm), maximum tuber length (cm) and maximum tuber depth (cm). The maximum tuber diameter, maximum tuber length and canopy height were taken using a tape measure. The depth was taken using a graduated bar. Cassava tuber yield and damaged (broken) tubers after harvest were determined using an electronic balance. The percentage of tuber breakage was calculated using ***Equation (4)***:

$$\text{Breakage} = \frac{\text{Mass of broken or damaged tubers (kg)}}{\text{Total tubers yield (kg)}} \times 100 \tag{4}$$

2-7. Uprooting Efficiency (U_ε)

The uprooting efficiency of the harvesting tool was evaluated using ***Equation (5)***.

$$U_{\mathcal{E}} = \frac{N_{Up}}{N_{UP} + N_{bk}} \times 100 \quad (5)$$

Nup, being the number of uprooted cassava tubers; Nbk, the number of broken tubers dug out of the soil, and U_ε (%), the uprooting efficiency of the harvesting tool.

2-8. Soil sampling

Nine replicates of soil samples at harvest were randomly taken for soil moisture content and bulk density determination at depths of 0-10, 10-20, 20-30 and 30-40 cm. Soil samples were oven dried at 105°C for 24 h for soil moisture determination [21]. Additionally, composite soil samples were taken and analyzed to determine their textural class, based on their respective sand, silt and clay content. The bulk density of the soil was calculated using the cylinder method to determine the specific bulk weight of a given volume of soil. The volume of the soil sample was immediately estimated from the volume of the cylinder while the soil weight was estimated after drying and weighing. The knowledge of these two variables allowed to calculate the bulk density according to the ***Relation*** :

$$da = \frac{\mathrm{P}}{\mathrm{V}} \quad (6)$$

da, is the bulk density (g cm^{-3}); P, the dry weight of the soil sample (g) and, V, the volume of the soil sample taken and dried.

The soil moisture determination was carried out in the relationship :

$$H = \frac{P_1 - P_2}{\mathrm{P}_1} \times 100 \quad (7)$$

H, is the soil moisture (%) at harvest; P_1, the wet weight of the soil and, P_2, the dry weight of the soil.

The soil samples were sieved with a 2 mm sieve to remove stones and dirts, before analysing the soil physical parameters in the laboratory. The particle size distribution (USDA textural triangle) was determined using calgon and water as dispersing agents as described by [22]. The clay dispersion index, clay flocculation index, aggregated silt and clay, and dispersion ratio were calculated using the [23] procedure as enumerated in ***Equations (8 - 11)***:

$$\text{Dispersion ratio (DR)} = \frac{\%\ \text{(silt+clay) in water}}{\%\ \text{(silt+clay) in calgon}} \times 100 \quad (8)$$

$$\text{Clay Dispersion Index (CDI)} = \frac{\%\ \text{clay in water}}{\%\ \text{clay in calgon}} \times 100 \quad (9)$$

$$\text{Clay Flocculation Index (CFI)} = \frac{\%\ \text{clay in calgon} - \%\ \text{clay in water}}{\%\ \text{clay in calgon}} \times 100 \quad (10)$$

$$\text{Aggregated Silt and Clay (ASC)} = \%(\text{clay} + \text{silt})\ \text{in calgon} - \%(\text{clay} + \text{silt})\ \text{in water} \quad (11)$$

3. Results

3-1. Soil properties

3-1-1. Particle size distribution at cassava harvest

The particle size distribution determined with and without calgon is shown in ***Table 1***. It has been observed that the treatment with calgon results in greater dispersion. As calgon is composed of sodium hexametaphosphate + sodium carbonate, the Na^+ ion reacts with the water to form a strong base, alkalising the medium and forming the hydroxide ion OH^-. Combining the latter with the H^+ ion leads to the loss of the H^+ ions adsorbed on the clays, which considerably reduces their flocculation. Consequently, the excess Na^+ ions have a strong dispersing effect on the clays. The soil at the Walungu experimental site was predominantly sandy in texture, whereas the soil at Uvira and Kabare was clayey. This suggests that the Walungu experimental site was coarser than Uvira and Kabare.

Table 1 : *Water dispersed and Calgon dispersed particle size distribution of soils of the experimental sites*

Sites	Water dispersed (g kg^{-1})			Calgon dispersed (g kg^{-1})			Texture
	Clay	Sand	Silt	Clay	Sand	Silt	
Walungu	153.2	526.8	320	233.2	506.8	260	Sandy
Uvira	283.2	366.8	300	393.2	196.8	310	clay-loam
Kabare	333.2	466.8	300	493.2	356.8	290	clayey

The variation in soil properties at Kabare, Uvira and Walungu is shown in ***Table 2***. There was a significant difference in the aggregated silt and clay content (ASC). ***Table 2*** shows that Walungu soils had 6 times less ASC than Uvira soils, the latter having 25 % less ASC than Kabare soils.

Table 2 : *Micro-aggregate stability indices of soils from Walungu, Uvira and Kabare at harvesting of cassava*

Sites	DR[a]	CDI[b]	CFI[c]	ASC[d]
Walungu	95.9	65.7	34.3	2.0
Uvira	82.9	72.0	28.0	12.0
kabare	80.8	67.6	32.4	15.0

[a] Dispersion ratio, [b] Clay dispersion Index, [c] Clay flocculation index, [d] Aggregated silt and clay.

In Uvira, the soils had the highest CDI (72.0 %), followed by Kabare (67.6 %), while the relative lowest CDI was recorded in Walungu (65.7 %). In contrast, the clay flocculation index (CFI) was highest at Walungu (34.3 %), while the lowest CFI (28.0 %) was recorded at Uvira behind Kabare (32.4 %). The results of the clay dispersion analysis revealed that dispersion ratio (DR) values were high at all experimental sites. For example, the DR value of the soils in Walungu was 95.9 %, the highest, while the DR value of the soils in Kabare was 80.8 %, the lowest. At Uvira, the DR value of the soils was 82.9 %. Dispersion ratios greater than 50 % are considered extremely dispersive, between 30 % and 50 % moderately dispersive, between 15 % and 30 % slightly dispersive and below 15 % non-dispersive.

3-1-2. Soil bulk density and soil moisture content at cassava harvest

Figure 5 presents the mean soil moisture content and soil bulk density versus soil depth at cassava harvesting time at the Kabare, Uvira and Walungu sites. It shows an increase in soil moisture with increasing depth at Uvira and Walungu, while at Kabare there is an invariable trend in soil moisture towards the entire soil layer (0 - 40 cm). At harvest, soil moisture ranged from 22.2 to 23.7 % at Kabare, from 1.3 to 3.0 % at Uvira, and from 9.7 to 10.8 % at Walungu, at increasing soil depths from 0 to 40 cm. ***Figure 5*** also shows a general increase in density with increasing soil depth.

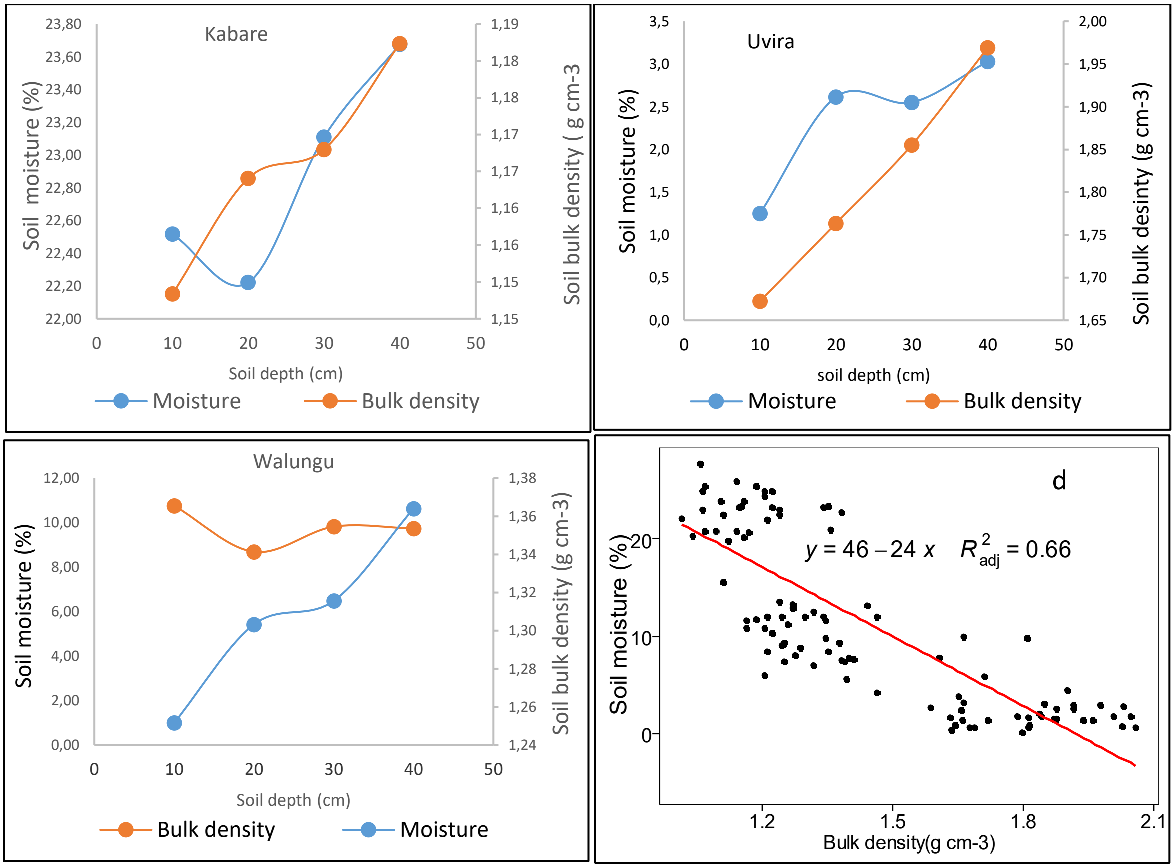

Figure 5 : *Graph of mean bulk density (g cm^{3}) and moisture content (%) at harvest versus soil depth for the three study sites (Kabare, Uvira and Walungu) and a graphical representation to illustrate the linear relationship between soil bulk density and soil moisture (d)*

The higher bulk density at harvest could be attributed to the fact that the soils were more consolidated. Soil bulk density at harvest varied from 1.15 to 1.2 g cm^{-3} at the Kabare site, from 1.7 to 2.0 g cm^{-3} at the Uvira site, and from 1.3 to 1.4 g cm^{-3} at the Walungu site, at increasing depths from 0 to 40 cm. Soil bulk density was lower at the Kabare site than at the Walungu and Uvira sites. The soil density at Uvira (approx. 2.0 g cm^{-3}) is indicative of a very heavy soil; so soil samples were taken when the soil was wetted to field capacity.

3-2. Effect of cassava yield on energy requirement for harvesting

Figure 6 shows the applied force during harvesting of cassava with three harvesting tools (hoe, lifter1 and lifter2) in three different cassava spacings (broadcast, 1 x 1 m, 2 x 0.5 m) at the Kabare, Uvira and Walungu sites. The force applied involved in harvesting cassava were significantly ($P = 0.05$) influenced by the site, spacing and implement used for harvesting as well as by the combination of site-implement-spacing between cassava plants. At the Kabare site, an average yield of 38 t Ha^{-1} was achieved by applying a force of 245 kN Ha^{-1} and doing work of 27 kJ Ha^{-1} with the hoe, followed by the lifter 2, which achieved an average yield of 36 t Ha^{-1} by applying a force of 171 kN Ha^{-1} and doing work of 20 kJ Ha^{-1}. The lifter1 with the highest applied force of 325 kN Ha^{-1} and the highest work done of 35 kJ Ha^{-1} to uproot the lowest average yield (26 t Ha^{-1}).

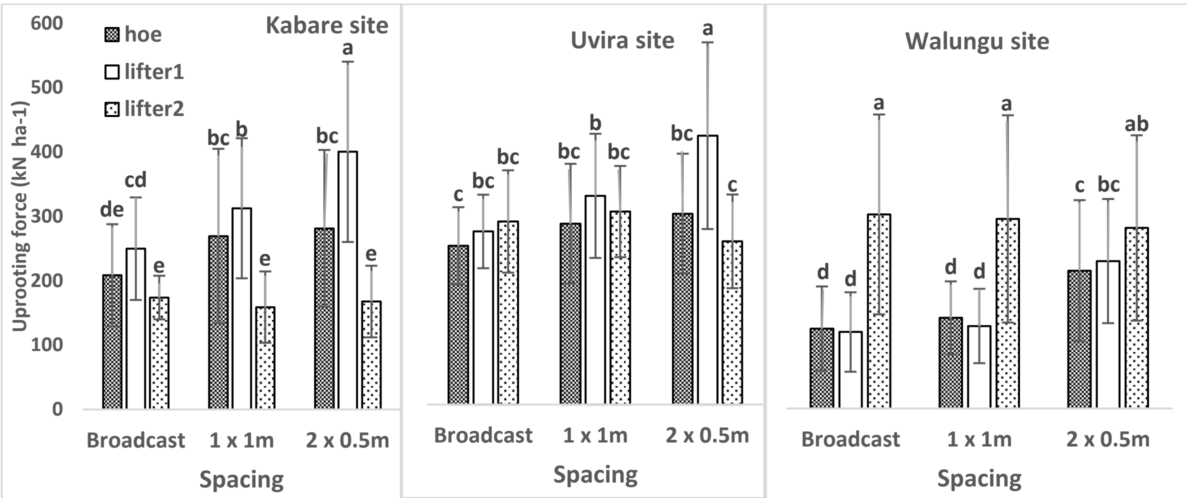

Figure 6 : *Cassava energy required (uprooting force) for harvesting using three tools (hoe, lifter1 and lifter2) under three different cassava spacing (broadcast, 1 x 1 m and, 2 x 0.5 m) in Kabare, Uvira and Walungu. Different characters in average mean different significantly among the treatments within the site using HSD test by Tukey-Kramer*

The highest value force for work done at the Walungu site was recorded for lifter2, with 24 kJ Ha^{-1} required to uproot an average yield of 15 t Ha^{-1}. This was successively followed by the lifter1 which required 19 kJ Ha^{-1} to uproot 8 t Ha^{-1} and the hoe (16 kJ Ha^{-1}) to uproot 7 t Ha^{-1}. In addition, the highest force of 141 kN Ha^{-1} to harvest with the lifter2, while the lifter1 required 107 kN Ha^{-1} and the hoe a force of 100 kN Ha^{-1}. At the Uvira site, there was a significant variation ($p = 0.05$) in cassava yield, applied force and work done during harvesting. There was also a significant ($p = 0.01$) interaction between the cassava spacing and harvesting tool. Here, lifter1 had the highest value for work done of 62 kJ Ha^{-1} to uproot an average yield of 40 t Ha^{-1}. The hoe was used next, requiring 45 kJ Ha^{-1} to uproot 30 t Ha^{-1}. The lifter2 (15 kJ Ha^{-1}) was then used to uproot 15 t Ha^{-1}. In addition, lifter1 required the highest force of 353 kN Ha^{-1}, while lifter2 required 254 kN Ha^{-1} and hoe required 251 kN Ha^{-1} to uproot 35 t Ha^{-1}.

3-3. Heart rate, applied force, work done, and harvesting capacity

When uprooting cassava, the force applied with lifter1 exceeded that of the hoe by 23 % and that of lifter2 by 24 %. In addition, the force applied with the hoe exceeded that of the lifter2 by 7 %. Later on, the work done by lifter1 exceeded that of the hoe by 15 % and that of lifter2 by 14 %. In addition, lifter1 recorded a lower heart rate (bpm) than the hoe (3 %) but higher than lifter2 (14 %). The hoe then recorded a heart rate that was 16 % higher than that of lifter2. In addition, the time taken to uproot the cassava with the lifter1 was 53 % longer than with the lifter2 and 19 % longer than with the hoe. The use of the hoe, however, led to a 42 % increase in the time taken for uprooting when using the lifter2. Our study revealed that one person can uproot cassava in 52.4, 64.6 and 30.6 days per hectare using a hoe, a lifter1 or a lifter2 respectively, assuming four hours of work per day. ***Figure 6*** shows that, at the Kabare site, the lifter2 recorded the lowest heart rate (78.9 bpm), corresponding to an energy consumption of 17.8 kJ and an applied force of 165.5 kN, while the hoe recorded the highest heart rate (88.7 bpm), corresponding to an energy consumption of 37.2 kJ and an applied force of 262.1 kN. The lifter1 recorded a heart rate of 87.6 bpm, corresponding to an energy consumption of 49.8 kJ and an applied force of 335.2 kN. At the Uvira site, the lifter2 recorded the lowest heart rate of 67.1 bpm, corresponding to the energy consumption (41.9 kJ) and applied force (296.6 kN), while both hoe and lifter1 recorded the highest heart rate of 85 and 84 bpm respectively, corresponding to the respective energy consumption of 30 and 29 kJ and a respective applied force of 327.2 and 330 kN. At the Walungu site, the lifter2 recorded the lowest heart rate (77.2 bpm) corresponding to the highest energy consumption (23.3 kJ) and applied force (135.6 kN), while the hoe and lifter1 recorded the highest heart rates of 97.8 bpm and 86.8 bpm respectively, corresponding to the lowest energy consumption of about 18 kJ and applied force of about 78 kN. ***Figure 6*** shows that harvesting cassava using the lifter2 has the greatest impact on heart rate across the three study sites. The discrepancy in energy and force observed in relation to the heart rate recorded with the lifter2 at all sites can be explained by the fact that grasping cassava at ground level remains difficult, particularly when the stem is weak. ***Figure 7*** shows that harvesting capacity varies significantly according to the interaction of site and harvesting tool type ($p = 0.05$). At Kabare (139.7 person-h Ha^{-1}), the harvesting capacity recorded by the lifter2 was 60.9 % less than that of the lifter1 (357.4 person-h Ha^{-1}) and 48 % less than that of the hoe (269.1 person-h Ha^{-1}). At Uvira, there was no significant difference in the harvesting capacity recorded by the three tools ($p = 5$ %). In Walungu, however, the capacity recorded by the lifter2 (194.2 person-h Ha^{-1}) was 15.3 % higher than that recorded by the lifter1 (168.4 person-h Ha^{-1}) and 3.0 % higher than that recorded by the hoe (188.5 person-h Ha^{-1}).

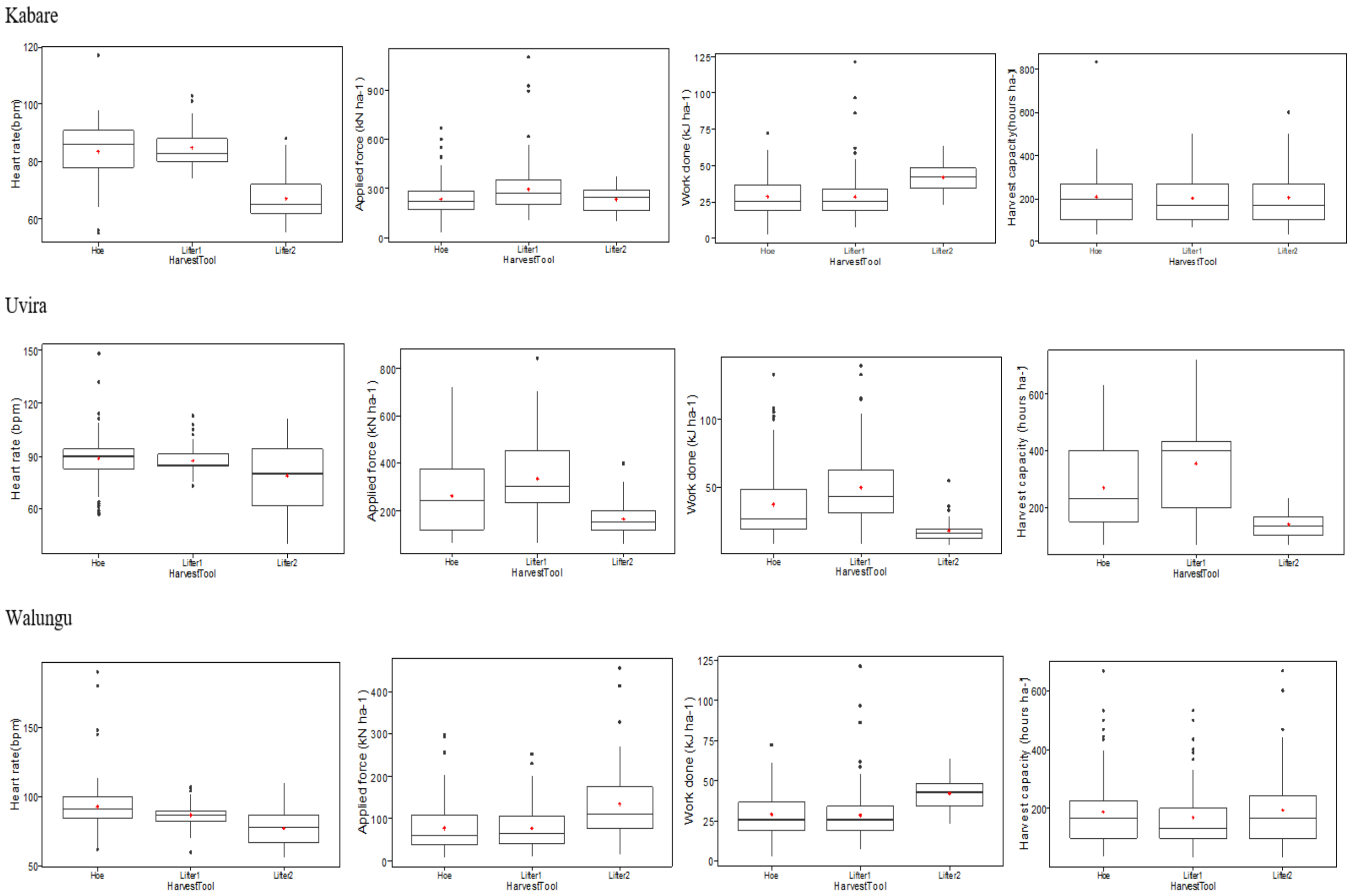

Figure 7 : *Average cassava harvesting force (kN Ha^{-1}), work done (kJ Ha^{-1}), heart rate (bpm) and harvesting capacity (person-h Ha^{-1}) for the three harvesting tools (hoe, lifter1 and lifter2). The horizontal line within each box is the median while the red diamond shape is the mean. The lower and upper limits of the boxes are the 25th and 75th percentile, respectively; the bars/moustaches below and above the box are the 10th and 90th percentile, and the points beyond the 10th and 90th percentiles are outliers. Trials were conducted at three sites named Kabare, Uvira and Walungu*

3-4. Relationship between energy requirement in harvesting and cassava yield

Figure 8 shows that the increase in yield resulted in an increase of the uprooting force and work done of harvesting Uvira, Kabare and Walungu.

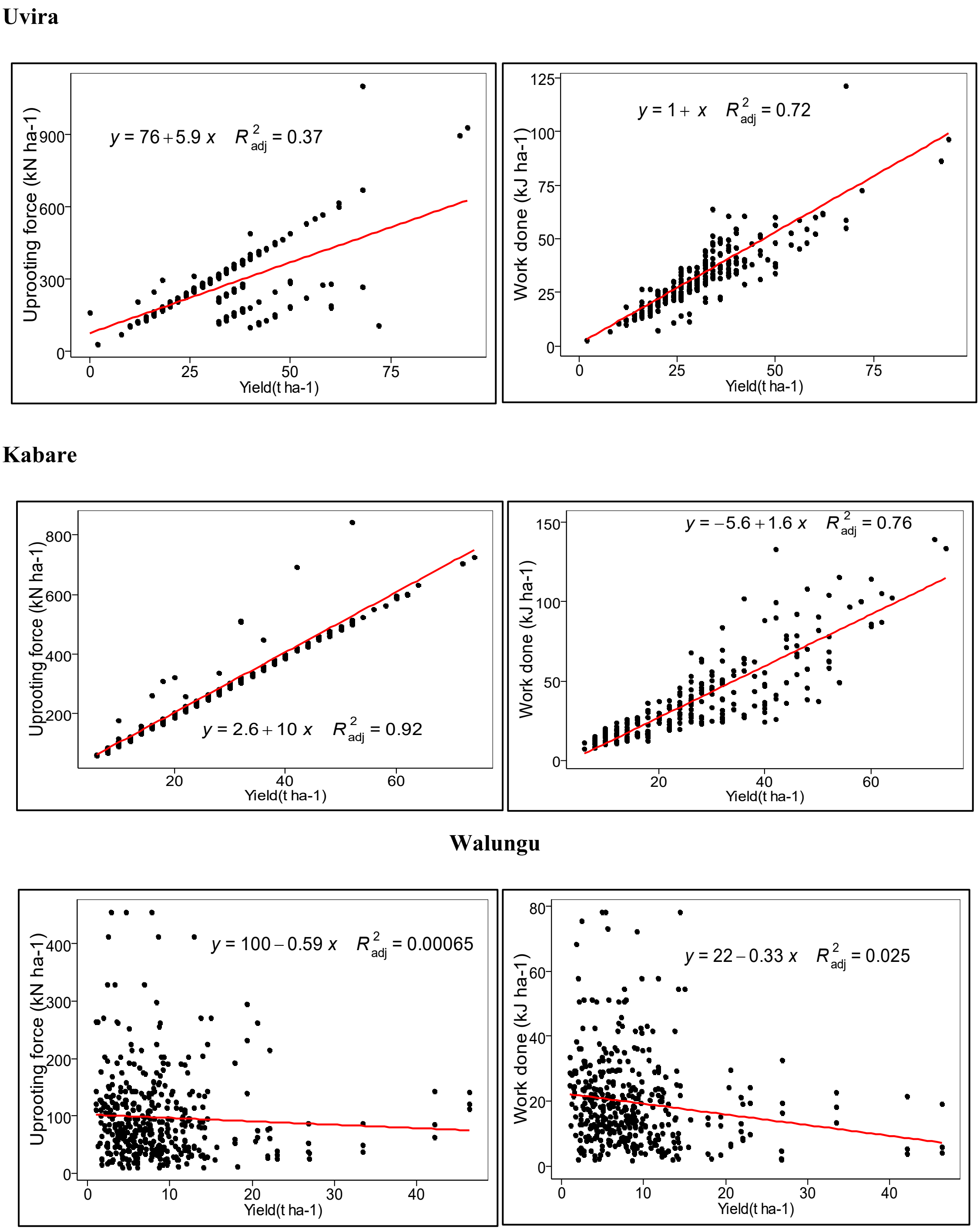

Figure 8 : *Graphical representation to illustrate the linear relationship linking energy required for harvesting cassava in relation with yield (t Ha^{-1}) at three sites (Kabare, Uvira and Walungu). The solid line is the linear regression curve (red)*

At Kabare, the lowest uprooting force (165.5 kN Ha^{-1}) with the corresponding work done (17.4 kJ Ha^{-1}) was found with lifter2 uprooting the lowest yield (15.8 t Ha^{-1}), while the highest force (335.2 kN Ha^{-1}) with the corresponding highest work done (49.8 kJ Ha^{-1}) was found with lifter1 uprooting the highest yield (32.4 t Ha^{-1}).

At Uvira, the lowest applied force (285.6 kN Ha^{-1}) with the corresponding work done of 28.7 kJ Ha^{-1} was found with the hoe uprooting the lowest cassava yield (29.2 t Ha^{-1}), while the highest applied force (327.2 kN Ha^{-1}) with the corresponding highest work done (41.9 kJ Ha^{-1}) was found with the lifter2 uprooting the highest cassava yield (33.3 t Ha^{-1}). At the Walungu site, the lowest applied uprooting force (77.8 kN Ha^{-1}) and corresponding work done (17.9 kJ Ha^{-1}) were found with lifter 1 to harvest the lowest yield (6.4 t Ha^{-1}), while the highest force (135.6 kN Ha^{-1}) and corresponding work done (23.3 kJ Ha^{-1}) were found with lifter 2 to harvest the highest yield (13.1 t Ha^{-1}). The relationship between uprooting force - yield and work done - yield was good for Uvira and Kabare, but very poor for Walungu. In the ferralitic soils of Walungu, the iron oxides strongly bind the P and form larger and larger crystals with it, contributing even more to the sand content of the soil. In this context, cassava is easy to harvest, especially when the soil is wet, as it does not stick to the tubers. The force with which soil particles adhere to cassava tubers is negligible.

3-5. Uprooting efficiency

Cassava uprooting efficiency by hoeing or lifting was assessed based on the percentage of damaged tubers in Kabare, Uvira and Walungu. ***Table 3*** shows that the highest damaged tubers varies from 23 to 39.8 % and from 24.1 to 61.3 %, respectively for hoe and lifter harvests of cassava. The relative higher tuber damage has been with the lifter1 at Kabare (25.8 %) and at Walungu (61.3 %). At the Uvira site, where the depth of tuber penetration was shallow, there were few damaged cassava tubers compared to the Walungu and Kabare sites. At the Walungu site, the higher level of tuber damage is thought to be due to tubers penetrating deeply into the soil combined with very low soil moisture levels. These two factors are suspected to contribute to the difficulty of harvesting cassava at the Walungu site. Evaluating uprooting efficiency showed that it generally ranged from 62.6–89.9 % across the sites. Regardless of the cassava spacing, the hoe uprooting efficiency ranged between 82.3-86.4 % at Uvira; between 81.8 - 85.2 % at Kabare, and between 72.4 - 77.8 % at Walungu. The lifer1 uprooting efficiency ranged between 76.4 - 85.0 % at Uvira; between 77.6 - 86 % at Kabare and between 62.6 - 70.2 % at Walungu. The lifter2 uprooting efficiency ranged between 79.8 - 83.2 % at Uvira; between 81.6-89.6 at Walungu, and between 63.8 - 77.9 % at Kabare. ***Table 3*** shows the effect of soil moisture content on the uprooting efficiency of the harvesting tool.

Table 3 : *Cassava tuber damage (%), uprooting efficiency (%) and soil moisture (%) at time of harvest for the Kabare, Uvira and Walungu sites by hoeing and lifting cassava*

Cassava plating	Uprooting tool	Uvira			Kabare			Walungu		
		Moisture (%)	Tuber damage (%)	Efficiency (%)	Moisture (%)	Tuber damage (%)	Efficiency (%)	Moisture (%)	Tuber damage (%)	Efficiency (%)
Broadcast	Hoe	8.0	23.0bc	83.1	22.5	21.4bcd	81.8	10.0	34.3fg	73.3
	Lifter1	8.0	24.1bc	85.0	22.3	25.8ab	84.5	9.7	54.9ab	67.7
	Lifter2	7.7	19.6c	83.2	22.0	10.8e	89.6	9.2	44.4cdef	63.8
1 x 1 m	Hoe	7.8	20.7c	82.3	22.5	17.6cde	83.8	10.0	37.4efg	74.7
	Lifter1	8.1	21.2c	80.8	22.7	30.6a	77.7	9.7	46.6bcde	64.9
	Lifter2	7.8	29.8ab	80.2	22.2	15.5de	85.6	9.3	47.2bcde	76.7
1 x 1 m + NPK	Hoe	8.1	17.5c	86.4	22.4	23.0bc	83.1	10.0	37.3efg	73.9
	Lifter1	8.1	21.8c	76.4	22.3	26.6ab	84.3	9.7	59.7a	62.6
	Lifter2	7.5	21.3c	81.5	22.3	19.6bcd	81.6	9.3	48.0bcd	77.9
2 x 0.5 m	Hoe	8.1	22.2c	84.8	22.3	19.6bcd	83,6	10.0	39.8defg	77.8
	Lifter1	7.9	18.1c	81.4	22.5	21.8bcd	86.0	9.8	61.3a	70.2
	Lifter2	7.9	29.6ab	80.9	22.1	14.8de	89.2	9.4	51.9abc	71.8
2 x 0.5 m + NPK	Hoe	7.9	18.3c	85.6	22.4	19.9bcd	85.2	10.0	33.9g	72.4
	Lifter1	8.1	17.4c	82.6	22.5	25.4ab	77.6	9.8	49.0bcd	65.5
	Lifter2	7.6	33.3a	79.8	22.0	19.9bcd	88.9	9.4	35.6fg	69.3
LSD										
Uprooting tool (A)		1.1ns	3.3***	2.0*	0.2**	3.3***	2.2***	0.1***	4.7***	2.2***
Cassava planting (B)		1.5ns	4.4ns	2.6ns	-	-	-	-	-	-
AxB		-	-	-	-	-	-		-	-

*Treatments with the same letter are not significantly different. LSD = Least standard deviation for the tools at 5 % of probability. Before manual harvesting, one field worker was tasked to uproot five cassava plants using a hand-hoe or the lifter harvesting tools (lifter1 and lifter2). Ns: not significant. *significant at p = 0.05. **significant at p = 0.01, ***significant at p = 0.001*

4. Discussion

Generally, soils which are coarse textured, could improve growth and yield performance of cassava since most cassava varieties cannot withstand prolonged waterlogged conditions [24]. It can be seen that the variation in soil sand, silt and clay fractions is site-specific ***(Table 1)***. In other words, the different soil texture classes in the experimental cassava fields reflect differences in the soil's parent material. This observation is consistent with the findings of [25]. However, over a very long period of time, paedogenesis processes such as erosion, deposition, eluviation, and weathering can change the soil texture. It can also be seen that soil bulk density tends to increase with increasing depths from 0 to 40 cm at the time of harvest across the three study sites. This trend is likely to hamper the cassava harvest. [26] indicate that this trend is attributed to the respective textural differences of the soils of these respective three study sites, since bulk density is influenced by soil texture. [9] claim that this trend is related to the decrease in water content in the soil profile, which likely makes soil particles more compact due to the elimination of additional voids. [2] reveal that soil moisture content and bulk density both have a negative but significant relationship with the force applied and labour required to harvest cassava. The implication is that farmers need an efficient tool at the right time to harvest cassava in the right way. [27] observed an optimum uprooting efficiency of 96.7 % at a soil moisture of 17 - 20 % with a cassava pusher harvester. Evaluating uprooting efficiency in this study shows that the uprooting efficiency ranged between 64 - 89.4% at a soil moisture of 7.3 - 22.7 %. Low soil moisture at harvest time resulted in higher cohesion, bulk density and compaction. These factors were identified as being responsible for the low uprooting efficiency. Other factors are, tuber depth and tuber spread, which lead to tuber damage as a result of the difficulty in uprooting the tubers [4, 28, 29]. In this study, a linear or polynomial relationship was observed between cassava yields, applied force and work performed during the cassava uprooting process. However, inconsistencies were noted with some work values with respect to respective yield, probably due to variations in bending strength along the length of the cassava tuber and its water content [27]. Nevertheless, the high R^2 values show that the linear and/or polynomial model is/are the good model to describe the variations in the variables (force and work) at Kabare (force : $R^2 = 0.92$, work : $R^2 = 0.73$) and Uvira (force : $R^2 = 0.39$, work : $R^2 = 0.73$). This is in contrast to the Walungu site with the lowest R^2 values (force : $R^2 = 0.00065$, work : $R^2 = 0.025$) using the linear model, the polynomial model (force : $R^2 = 0.007$, work: $R^2 = 0.029$) being a good model to represent the variation in force and work. [30] obtained similar results using the polynomial model. In line with our results, [2] deduced from the significant positive relationship between yield and work done, that an increase in yield would lead to a corresponding increase in energy requirements for harvesting cassava. The results of this study are also comparable with those of [15], who reported a significant and positive correlation between the required applied harvesting force and the yield per plant and number of tubers. Since each site and field has its own conditions and history, the choice of cassava harvesting tool must be selective. If the soil is not too hard, the tubers can be easily lifted using lifter1.

However, harvesting cassava with lifter1 in wet soil is detrimental, as it rests on three feet that can sink. Also, by harvesting cassava with lifter1, tubers might be broken or lost if the tuber-lifting velocity was improper for cassava harvesting in soils having different hardness, which would result in poor harvesting quality. Despite its effectiveness in gripping the cassava plant at the collar, the weight of lifter1 (14 kg) puts it at a disadvantage compared with lifter2 (2.4 kg), and makes it difficult to move around the field. When uprooting cassava, the time taken to uproot the cassava with the lifter1 was 53 % longer than with the lifter2 and 19 % longer than with the hoe. The hoe, on the other hand, increased the uprooting time with the lifter2 by 42 %. Our study also showed that one person can uproot cassava in 52.4 days per hectare with the hoe, 64.6 days per hectare with the lifter1 and 30.6 days per hectare with the lifter2, assuming 4 hours of work per day. Seen from this angle, the lifter2 can be designated for cassava harvesting, as the hoe is generally considered tedious, labour-intensive and unsuitable for large-scale production [28, 31, 32]. But actually, some adjustments are currently needed to strengthen the grip around the cassava stalk at ground level. In addition, if hoe harvesting takes place mainly in wet clayey soil conditions the soil sticks to the hoe during harvesting. As a result, the force applied by the operator and the energy deployed to uproot the cassava increases. [4] assert that the properties of applied force and work done are important data required for choosing a harvesting tool. Referring to the calculations of [33] and the Physical Activity Guidelines Advisory Committee [34], our findings show that lifting (lifter1 or lifter2) is a moderate-intensity physical activity, whereas harvesting cassava with a hoe is a vigorous-intensity activity. However, adjustments are currently needed to improve grip around the cassava stalk at ground level when lifting cassava (lifter1 or lifter2). This study shows that lifter1 recorded a lower heart rate (bpm) than the hoe (3 %), but a higher heart rate than lifter2 (14 %). The hoe recorded a heart rate that was 16 % higher than that of lifter2. This is because the hoe is first used to loosen the soil around the tubers before they are pulled out and detached from the base of the plant by hand, after the upper parts of the stem and leaves have been removed. This process is very time-consuming and energy-intensive. The lifter2, however, had an advantage because its weight of 2.4 kg makes it possible for even women and children to easily operate and use the tool for manual cassava harvesting. The harvesting capacity of lifter2 is between 30.6 person-days per hectare (considering to 4 hours of work per day), which is comparable to the claims of [11], which range from 22 to 62 person-days per hectare, or the claims of [9] ranging from 11.1 to 31.9 person-days per hectare. The use of an improved harvesting tool, such as the lifter2, resulted in a 50 % reduction in the time taken to manually uproot cassava by hoe [9]. In deep-tuber conditions, the hoe requires sufficient time, strength and energy, but causes less tuber damage. This phenomenon is attributed to soil dynamics and tuber shape [2]. Finally, the lifter2 can uproot cassava tubers deep in the soil with a water content ranging from 8 % to 22.5 % in record time while keeping the heart rate as low as possible. Hence, the lifter2, for some adjustments, can be considered as an effective alternative harvesting tool of the traditional harvesting cassava tool, the hoe, throughout the eastern DRC.

5. Conclusion

The study reveals the potential for reducing time, energy and labour, as well as damage to tubers. Using the lifter1 took 53% more time than using the lifter2 and 19% more time than using a hoe to uproot the cassava. Conversely, using a hoe increased the time taken to uproot cassava with the lifter2 by 42%. Using a hoe also resulted in a heart rate that was 16% higher than that recorded using the lifter2. Additionally, the force recorded by the lifter2 was 7% lower than that recorded by the hoe. Overall, our results suggest that lifting is a moderate-intensity activity, whereas cassava harvesting with a hoe is vigorous. However, adjustments are needed to improve the grip on the cassava stalk at ground level when lifting it (using either lifter1 or lifter2). These adjustments would improve the efficiency of cassava harvesting and enable local farmers to work more comfortably and productively.

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